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Effect of N Rate and Tillage on Yield, N Accumulation and Leaf N Concentration of Grain Sorghum[1]

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ABSTRACT

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Conservation tillage is an accepted method of decreasing soil erosion. However, limited information is available concerning N fertilizer requirements of grain sorghum (*Sorghum bicolor* L. Moench) grown under reduced-tillage management. Tillage effects on sorghum yield and N accumulation in 1985 and 1986 were studied on a Weswood soil (Fluventic Ustochrept) near College Station, Texas (Latitude 30° 35′N, Longitude 96° 21′W). Four N rates (0, 50, 100 and 150 kg N ha^{-1}) were applied to plots managed with no-tillage or conventional tillage. Response of grain yield to N rate was curvilinear while that of stover yield was linear. However, tillage and N interactions also influenced grain and stover yield. At low N rates, conventional tillage produced more stover and grain, but at higher rates tillage differences did not occur. Both tillage systems attained maximum grain yield at 122 kg N ha^{-1} as determined by regression analysis. Nitrogen accumulation in both stover and panicles was linear with N rate. Lower whole-plant N accumulation with no-tillage at low N rates supported the contention that N was less available in no-tillage soils. Leaf N concentration at anthesis was higher in conventional-tillage treatments. However, a regression of leaf N concentration on N rate predicted a maximum leaf N concentration of 34 g N kg^{-1} at 164 kg N ha^{-1} for both tillage treatments. When grain yield was regressed on leaf N concentration for each tillage treatment, maximum yield occurred at leaf N concentrations of 32 and 37 g kg^{-1} for conventional tillage and no-tillage, respectively. Leaf area index measured at anthesis significantly increased with N rate and was greater in conventional tillage. Leaf N concentration and leaf area index were positively correlated with grain yield. Data from this study suggest that fertilizer N amendments to no-tillage sorghum in excess of that required for maximum conventional-tillage yields are not necessary.

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INTRODUCTION

Grain sorghum is a major crop worldwide because of its adaptation to a wide spectrum of climatic and soil-fertility regimes. Drought-resistance characteristics of sorghum allow it to be grown in dry regions where high summer temperatures and low rainfall prevent economical production of less tolerant crops.

In areas where moisture conservation is a primary concern, reduced-tillage management may be a beneficial alternative to conventional tillage and may result in reduced soil erosion and energy input. However, the soil environment generated by reduced tillage may require greater fertilizer input. A combination of factors may contribute to a deficiency of available inorganic nitrogen (N) in reduced-tillage systems. Surface accumulation of organic residues in no-tillage soils serves as a barrier for water evaporation, furnishing a moist environment conducive to increased microbiological activity (Doran, 1980). Reduced-tillage soils dry slowly and maintain lower soil temperatures following cool, wet periods, which may retard mineralization and nitrification activity. In this environment, facultative organisms capable of denitrification and anaerobic metabolism may comprise a large proportion of the microbial population (Doran, 1980; Rice and Smith, 1982; Linn and Doran, 1984; Aulakh et al., 1984). With time, improved structural aggregation and formation of macropores may increase infiltration in reduced-tillage soils (Ehlers, 1975; Edwards, 1982), with subsequent enhanced leaching of mobile ions such as NO_3^- in excess drainage water (Thomas et al., 1973). The slow release of nutrients, ion leaching, accumulation of organic residue and lessened disturbance of the plow layer in reduced-tillage soils all decrease N availability (Dick, 1983).

Nitrogen limitations in reduced-tillage systems may be countered using various management strategies. Supplying fertilizer in excess of rates normally used for conventional-tillage systems is a common practice (Moschler and Martens, 1975). The N fertilizer rate prescribed for a no-tillage system is often based upon the amount necessary for conventional tillage plus some arbitrary percentage. The percentage varies among states but ranges from about 10 to 20% (Phillips et al., 1980; Buchholz and Hanson, 1982). Fertilizer placement below the surface may reduce NH_3 volatilization and nutrient immobilization (Mengel et al., 1982; Reinertsen et al., 1984; Fox et al., 1986). Placement in proximity to roots also eliminates the need for rain to leach fertilizer to the root zone, as is the case when fertilizer is surface broadcast.

Relatively little information has been published concerning fertilizer N levels necessary to produce optimum no-tillage sorghum yields. Most work accomplished in the last decade on reduced-tillage N fertilizer management has involved corn (*Zea mays* L.) or wheat (*Triticum aestivum* L.). Reduced-tillage fertilizer research with dryland sorghum has largely been neglected in spite of its adaptation to areas where moisture conservation is a primary management objective.

Objectives of this study were to measure N uptake by conventionally-tilled and no-tilled sorghum where fertilizer N was applied at varying rates and to evaluate the effect of N accumulation on grain and stover yields for each tillage system.

MATERIALS AND METHODS

The study was conducted in 1985 and 1986 at the Texas A & M University Research Farm in Burleson County, Texas (Latitude 30° 35′N, Longitude 96° 21′W). The soil was calcareous (pH 8.2), low in organic matter (1%), and classified as a Weswood silt loam soil (fine-silty, mixed, thermic family of Fluventic Ustochrepts). Long-term average sorghum growing-season rainfall (March through July) is 444 mm. Additional precipitation information is reported in Table 1. Sorghum was seeded into conventional-tillage or no-tillage managed plots at a rate to achieve 160 000 plants ha^{-1} with 1-m row spacing. The hybrid used was 'Funks G522DR'.

The experimental design was a randomized complete block arranged as a split plot. Method of tillage was the main plot effect, with combinations of N rate and method of placement as split plot effects. Placement and tillage×placement interaction effects are included in the statistical analysis for this paper, but are discussed in another paper (Locke and Hons, 1988). Ammonium nitrate (NH_4NO_3) fertilizer was applied 2 weeks post-emergence at 0, 50, 100 and 150 kg N ha^{-1}. The surface area for each main plot was 390 m^2

TABLE 1

Rainfall for Burleson County site, 1985 and 1986

Month	1985 (mm)	1986 (mm)	50 year average (mm)	Percentage of average	
				1985 (%)	1986 (%)
January	68.3	26.4	75.4	90.6	35.0
February	89.7	52.1	76.5	117.3	68.1
March	55.6	15.7	73.9	75.3	21.3
April	33.3	53.3	96.0	34.7	55.6
May	130.8	220.0	125.0	104.7	176.0
June	29.2	103.1	79.5	36.7	129.7
July	58.4	58.2	69.1	84.6	84.2
August	14.0	102.9	56.4	24.8	182.4
September	108.5	147.6	63.0	172.2	234.3
October	201.2	119.6	80.5	249.8	148.6
November	131.3	74.7	84.1	156.2	88.8
December	45.2	144.3	98.3	46.0	146.8

(24.4×16 m), while the area for each split plot was 48.8 m^2 (12.2×4 m). Each treatment combination was replicated 4 times.

The study area was disked and bedded in autumn 1984, and wheat was planted as a cover crop. Prior to planting sorghum in spring 1985, the wheat in no-tillage plots was killed with paraquat (1,1′-dimethyl-4,4′-bipyridinium ion, 1.12 kg a.i. ha^{-1}). Conventional-tillage plots were disked and bedded prior to sorghum planting. A conventional planter was used to seed the sorghum, with coulters added to facilitate seeding directly into previous crop residue on no-tillage plots. Alachlor (2-chloro-N- (2,6-diethylphenyl)-N- (methoxymethyl) acetamide, 1.12 kg a.i. ha^{-1}) and propazine (6-chloro-N,N′-bis(1-methylethyl)-1,3,5-triazine-2,4-diamine, 2.24 kg ha^{-1}) were applied pre-emergence for weed control. Carbofuran (2,3-dihydro-2,2-dimethyl-7-benzofuranyl methylcarbamate 6 kg a.i. ha^{-1}) was applied at planting for early season insect control. Fenvalerate (Cyano(3-phenoxyphenyl) methyl-4-chloro-alpha-(1-methylethyl) benzene acetate) was applied during anthesis to control insects, particularly sorghum midge (*Contarina sorghicola*).

Conventional tillage plots were disked and bedded after harvest in autumn 1985 and reshaped in the spring, just prior to planting. Both tillage treatments remained fallow during the winter, following harvest in 1985.

Leaf samples (third leaf from top) were collected at anthesis (50% bloom) (Lockman, 1972). Fifteen leaves were sampled from each plot. Leaf area on all green leaves from two plants removed at anthesis was measured with a portable area meter. Four whole plant samples were removed from each plot at harvest. The whole-plant samples were separated into panicles and stover (stems + leaves). A 10-m section of a middle row was mechanically harvested for grain from each plot. Stover was harvested by hand from 3 m of row for estimation of stover production.

Samples were oven-dried at 60°C, weighed, ground to pass a 1-mm sieve, and digested in H_2SO_4 (Nelson and Sommers, 1980). Total Kjeldahl N was determined on aliquots of sample digest using an autoanalyzer (Technicon, 1977).

Data from both years were pooled for statistical analysis with year representing the split–split effect (Little and Hills, 1978). Analysis of variance procedures were used to detect treatment effects. Separation of means was accomplished using Fisher's least square difference method (Steele and Torrie, 1960). Regression procedures were used to model crop response to N rate.

RESULTS AND DISCUSSION

Tillage had no effect on grain or stover yields across all N rates (Table 2). However, the interaction of tillage and N rate was significant for both grain and stover yields, although it was significant for grain yield only at the 0.10 probability level. The trend for grain production was for lower yields on no-

TABLE 2

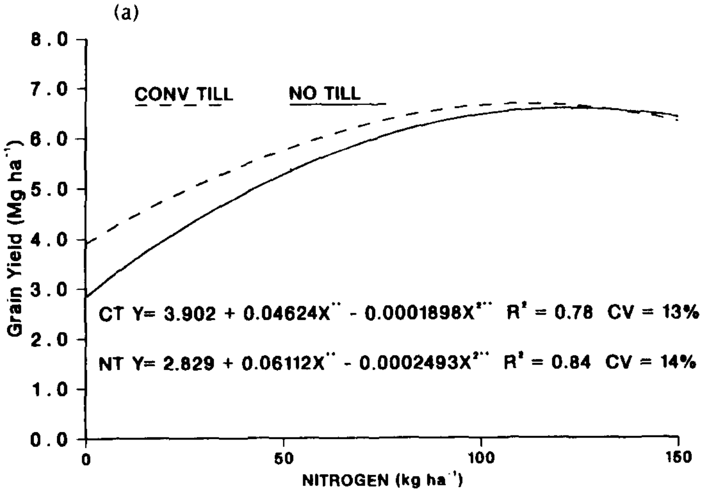
Analysis of variance results for combined years

Source[1]	df	Stover N	Panicle N	Whole-plant N	Leaf N	Stover yield	Grain yield	Leaf area index (LAI)
Till	1	*	NS	*	0.08	NS	NS	*
Block	3	*	*	*	NS	**	NS	**
Error a	3							
Placement	1	**	**	**	**	*	0.06	NS
N	3	**	**	**	**	**	**	**
N×P	3	NS	NS	NS	NS	NS	NS	NS
T×P	1	NS	NS	NS	NS	NS	NS	NS
T×N	3	NS	NS	0.09	NS	*	0.10	0.09
T×N×P	3	NS	NS	NS	NS	NS	NS	NS
Error b	6							
Year	1	NS	**	**	**	**	**	**
T×Y	1	NS	NS	NS	NS	NS	NS	NS
P×Y	1	NS	NS	NS	NS	NS	NS	NS
N×Y	3	NS	NS	NS	NS	*	*	NS
T×P×Y	1	NS	NS	NS	NS	NS	NS	NS
N×T×Y	3	NS	NS	NS	NS	NS	NS	NS
N×P×Y	3	NS	NS	NS	NS	NS	NS	NS
N×T×P×Y	3	NS	NS	NS	NS	NS	NS	NS
Error c	84							

*Indicates the effect is significant at a probability level of 0.05; **indicates the effect is significant at a probability level of 0.01; NS indicates the effect is not significant at a probability level of 0.10.
[1]T = Tillage; N = nitrogen; P = placement; Y = year.

tillage at lower N rates, but no differences owing to tillage at the higher N rates (Fig. 1a). This trend was most obvious in unfertilized plots where soil N apparently was most limiting, but also occurred at the 50 kg N ha^{-1} rate. A similar response was observed for stover yield. The grain yield response to N rate was curvilinear, (Fig. 1a), while a linear response model gave the best fit for stover yield (Fig. 1b). Maximum predicted grain yield for both conventional tillage (6.718 Mg ha^{-1}) and no-tillage (6.575 Mg ha^{-1}) occurred at 122 kg N ha^{-1}.

The main effect of tillage was significant for stover and whole-plant N accumulation, but not for panicle N accumulation (Table 2). Stover and whole-plant N accumulation in conventional-tillage treatments was higher than in no-tillage treatments across all N rates (Table 3), indicating a possible limitation in N availability in no-tillage soils. This limitation was also suggested by the greater linear N coefficient for no-tillage grain and stover production (Fig. 1). Tillage did not significantly affect N accumulation in the panicle, possibly because the panicle was the major N sink during reproductive growth.



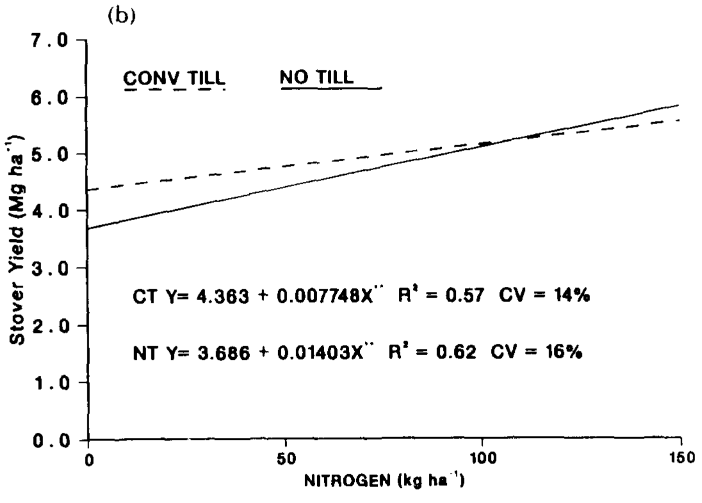


Fig. 1. Fitted regression lines and equations depicting the effect of the interaction between N rate and tillage on (a) grain yield and (b) stover yield. **Indicates significance at a probability level of 0.01.

In cases of N limitation, N is preferentially allocated from stover to the panicle, probably resulting in the observed lower N accumulation in no-tillage stover. Although not statistically significant, the trend was for higher N accumulation in panicles from conventional-tillage plots.

Tillage significantly influenced leaf area index, but the effect on leaf N concentration was significant only at a probability level of 0.08 (Table 3). Nitrogen apparently was less available in no-tillage treatments at anthesis since leaf N concentration and leaf area index in conventional-tillage treatments tended

TABLE 3

Effect of tillage on leaf N concentration and leaf area index (LAI) at anthesis and panicle, stover and total N accumulation at harvest

Tillage	Leaf N (g N kg^{-1})	LAI	N uptake kg N ha^{-1}		
			Panicle	Stover	Whole plant
Conventional tillage	31.2[a1]	4.69[a2]	91.5NS[3]	44.8[a]	136.3[a]
No tillage	29.1[b]	4.32[b]	80.9NS	37.5[b]	118.4[b]

[1]Means within leaf N followed by the same superscript are not significantly different by LSD at a probability level of 0.08.
[2]Means within LAI, stover N and whole-plant N followed by the same letter are not significantly different by LSD at a probability level of 0.05.
[3]NS indicates nonsignificance.

TABLE 4

Effect of N rate on leaf area index (LAI) at anthesis and grain and stover yields at harvest averaged across years

N rate (kg N ha^{-1})	LAI	Grain yield (Mg ha^{-1})	Stover yield (Mg ha^{-1})
0	3.30[a1]	3.322[a]	3.867[a]
50	4.47[b]	5.631[b]	4.768[b]
100	5.18[c]	6.408[c]	5.189[c]
150	5.05[c]	6.521[c]	5.541[d]

[1]Means within a column followed by the same superscript are not significantly different by LSD at a probability level of 0.05.

to be higher than in no-tillage treatments across all levels of N application. The tillage effect on leaf area index may reflect the observed slower early season growth and establishment of no-tillage sorghum. Negative effects of delayed growth on leaf area may have been compounded by N stress.

A significant positive response of grain and stover yields (Table 4) and panicle, stover and whole-plant N uptake (Fig. 2) to N rate was indicated across tillage treatments. Trends associated with N rate effects on yield were previously discussed. Panicle N accumulation increased more readily with N rate than stover N uptake. The higher slope associated with the panicle N uptake regression indicated that the panicle was the major sink for N during reproductive growth. Much of the N present in the panicle at harvest was remobilized from vegetative tissue. A relatively flat response of stover N accumulation to N rate reflected only maintenance N requirements. The slope of the curve for whole-plant N accumulation was therefore influenced more by panicle N accumulation than by stover N accumulation.

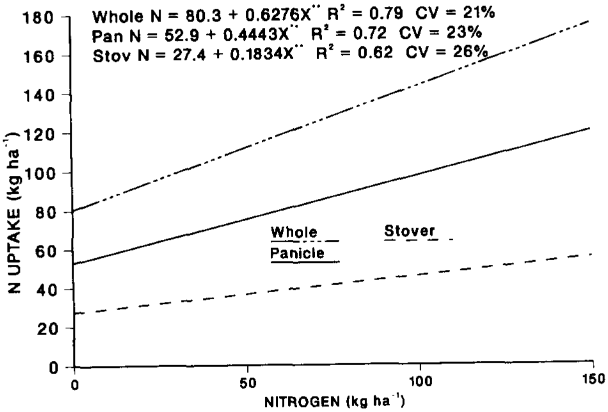


Fig. 2. Fitted regression lines and equations depicting the effect of N rate on N accumulation in panicle, stover and whole plant. **Indicates a probability level of 0.01.

Although the tillage effect on grain and stover yields was the same for both years, a significant difference in grain and stover yield response to N rate was observed between years (Table 2). Grain yield response was curvilinear for both study years, while stover response was linear (Table 5). Grain and stover yields in 1985 were higher than in 1986 at each level of N. Grain production in 1985 increased with N rate to a maximum of 7.331 Mg ha^{-1} at 135 kg N ha^{-1}, while maximum grain yield (6.021 Mg ha^{-1}) in 1986 occurred at 111 kg N ha^{-1}. Limiting moisture conditions during plant emergence and establishment in 1986 (total precipitation March and April: 88.9-mm rainfall in 1985 vs. 69-mm rainfall in 1986) probably resulted in overall lower yields in 1986, with maximum yield achieved at a lower N level than in 1985. Residual fertilizer from the prior year and N mineralization from organic material were probably not major factors in 1986 causing maximum yield and N uptake to occur at a lower N fertilizer level than in 1985.

TABLE 5

Regression of grain and stover yield on rate of fertilizer N in 1985 and 1986

Plant component	Regression equations		
Stover			
1985	$Y=4.120+0.01341N^{**}$	$R^2=0.62$	CV=15%
1986	$Y=3.929+0.008373N^{**}$	$R^2=0.48$	CV=16%
Grain			
1985	$Y=3.603+0.05541N^{**}-0.0002059N^{2**}$	$R^2=0.79$	CV=14%
1986	$Y=3.128+0.05195N^{**}-0.0002332N^{2**}$	$R^2=0.78$	CV=13%

**Variables in a model are significant at $P<0.01$.

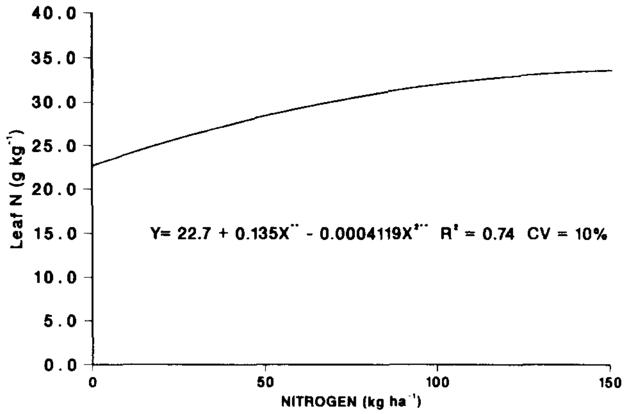


Fig. 3. Fitted regression line and equation depicting the effect of N rate and N concentration in the third leaf at anthesis. **Indicates a probability level of 0.01.

The positive response of leaf N concentration and leaf area indices to N rate at anthesis reflected improved N nutrition of the plant with increasing fertilizer application rate (Table 2). Leaf area index increased with N rate up to 100 kg N ha^{-1}, after which it remained the same (Table 4). Regression of leaf N concentration on N rate (Fig. 3) indicated that the calculated maximum leaf N concentration would occur at 164 kg N ha^{-1}, which is above the maximum N rate applied in this study.

Leaf N concentration and leaf area index were positively correlated (Table 6). Both leaf N concentration and leaf area index were positively correlated with grain and stover yield, however, relationships with leaf N concentration resulted in greater correlation coefficients. Information concerning interactive effects of leaf area index and N on sorghum grain production is limited. Jones (1985) cited a study which demonstrated the negative effect of N stress on leaf area, and Swanson (1941) linked leaf area to grain production. Regression of grain yield on leaf N concentration (Fig. 4) indicated maximum yield was at-

TABLE 6

Correlation coefficients for leaf N concentration, leaf area index (LAI), stover yield and grain yield

	Correlation coefficients		
	LAI	Stover yield	Grain yield
LAI	–	0.32**	0.38**
Leaf N	0.68**	0.63**	0.71**

**Indicates coefficients are significant at $P<0.01$.

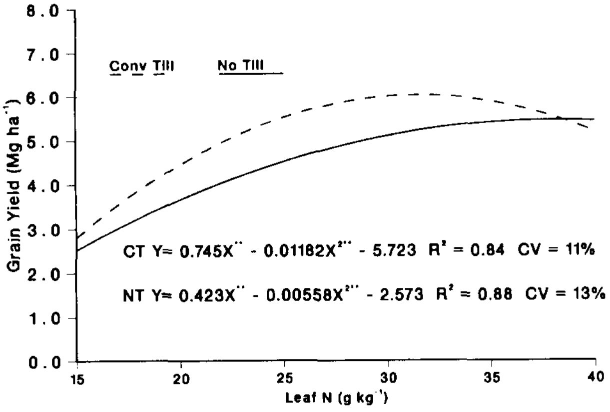


Fig. 4. Regression equations and fitted lines depicting the relationship of grain yield and leaf N concentration. **Indicates probability level of 0.01.

tained at leaf N concentrations of 32 and 37 g kg^{-1} for conventional tillage and no-tillage, respectively. These values compare favorably with the N concentration in the third leaf at bloom stage as reported by Lockman (1972) and Brawand and Hossner (1976).

CONCLUSIONS

Results from this study demonstrated that N is more likely to be limiting to grain-sorghum production under no-tillage than under conventional tillage. The cultivation involved with conventional-tillage management apparently enhanced mineralization and supplemented soil N not provided by fertilizer. This result was most apparent at low N rates. Both tillage treatments achieved maximum production at 122 kg N ha^{-1}, implying that for this soil, provision of adequate fertilizer enabled the no-tillage sorghum to overcome limitations in soil N availability. These data suggest that fertilizer N amendments to no-tillage sorghum in excess of that required for maximum conventional-tillage yields are not necessary.

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